



Trace Element Mapping of Fish Otoliths Using Synchrotron Microbeam X-ray Fluorescence as an Indicator of Fish Movement in the Illinois River System

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Abstract

The goal of the study was to use trace element content to determine the migratory patterns of the Silver and Bighead Carp in the Illinois river system and its tributaries. These species of Asian Carp are considered invasive to this region. These fish populate the Midwest region of the States and are destructive to the natural ecosystems throughout. Their feeding habits starve the native species which reside in the rivers and lakes by outcompeting them for available food supplies.

Migratory patterns can be constrained by measuring trace element content within fish otoliths. Otoliths are calcareous biomineral structures found in the inner ear of fish used for orientation. Otoliths accrete calcium carbonate continuously over time, resembling tree rings, with the most outer zones being the youngest. The goal of the experiment was to analyze the concentrations of known trace element (e.g. Strontium) using synchrotron X-ray fluorescence microprobe and compare measured Sr/Ca to the ratio found in regional water bodies. Comparing the otoliths’ strontium concentrations to known concentrations of Strontium in the Illinois river system, we were able to conclude that Silver Carp were more migratory and likely to move downriver to the Mississippi River.

Introduction

Asian carp is an invasive species in North America and growing problem in U.S. waterways that require effective management practices to mitigate their impact on native species and ecosystems. To manage them effectively a better understanding of migratory habits for individual species that are collectively lumped under the categorization of Asian carp is needed. Bighead carp and Asian carp are just two of many species categorized as Asian carp and have recently discovered in the upper Illinois River system.

In this study, we have evaluated the relative migratory patterns from these two distinct species using trace element otolith microchemical analysis. Otoliths are composed of calcium carbonate. The alkali earth metal Sr readily substitutes in to the CaCO_3 structure. The Sr/Ca ratio of each otolith layer is thought to be proportional to that of the ambient water which the migrating fish inhabited. Synchrotron μXRF analyses of these otoliths were conducted using the GSECARS 13-ID-E X-ray microprobe beamline.

Methods

Whole otoliths were provided by Dr. Greg Whitledge from Southern Illinois University, extracted from silver and bighead carp collected from the Illinois River near Morris, IL in 2013. Otoliths were embedded in epoxy and then sectioned using a diamond saw to $\sim 50 \mu\text{m}$ in thickness (Figures 1-3 right). They were then glued to quartz microscope slides and polished for analysis at the beamline. A focused spot size of $2 \mu\text{m}$ was used with an incident beam energy of 18.9 keV. Otoliths were compositionally mapped using continuous scanning with a pixel size of $3 \mu\text{m}$ and a scan time per pixel of 20 msec. Compositional maps of the Sr K α fluorescence intensity measured in each otolith were produced using the GSECARS MapViewer software (Figures 1-3 left).

Discussion

Maps of the strontium fluorescence intensity in each otolith are shown in Figures 1-3 (left). In the color table chosen for the maps, blue represents lower concentrations and red the highest. Figure 4 shows the measured Sr counts numerically along a transect through each individual otolith (labeled A-A’ on Figures 1-3). Although Sr was highly concentrated in all the otoliths analyzed, the maximum Sr intensity was 2-3x higher in silver carp otoliths compared to bighead carp otoliths. Additionally, silver carp otoliths vary in Sr concentration by a factor of 5-6x from lowest to highest Sr bands whereas in the bighead carp otolith Sr concentration varies only by a factor of ~ 1.5 throughout the bands.

Results

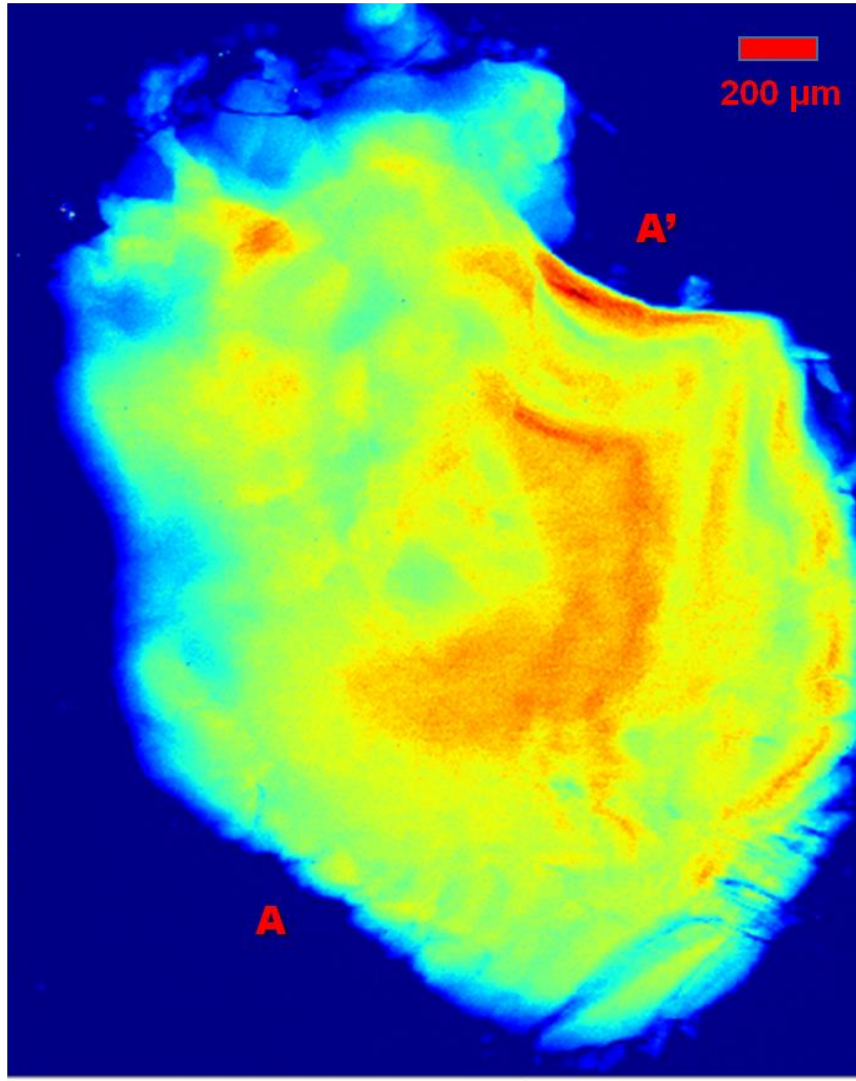


Figure 1: Sample B1 - Bighead Carp Otolith (Left) Sr K α intensity, blue = low, red = high. (Right) Reflected light photomicrograph.

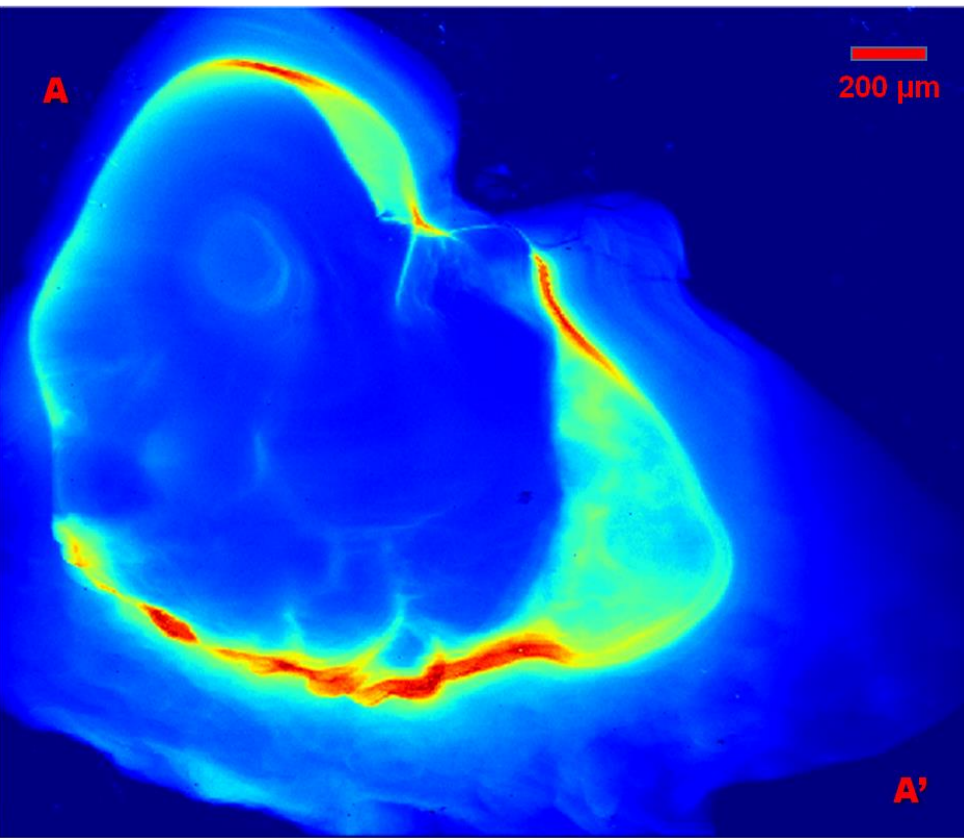
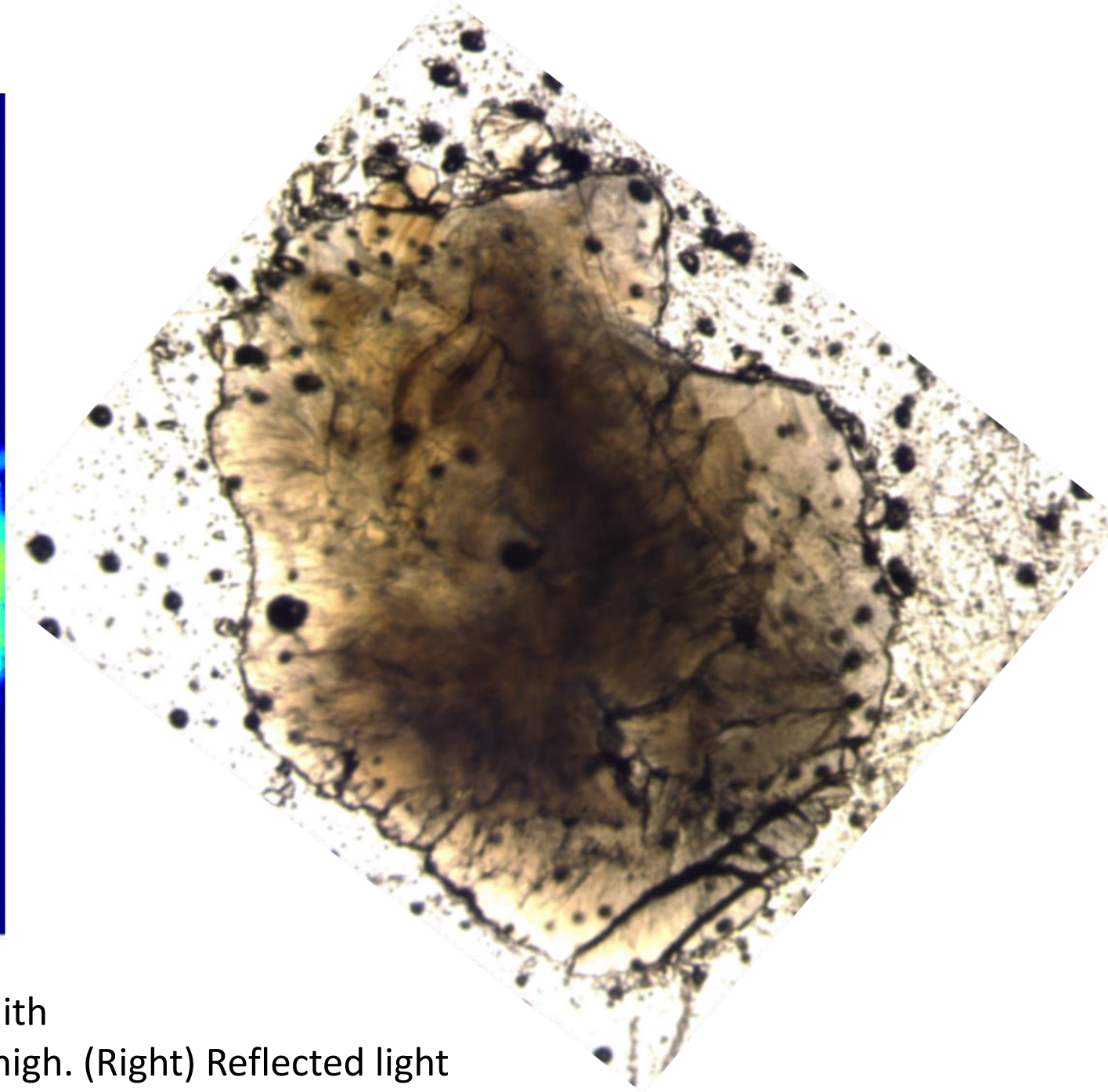


Figure 2: Sample S2 - Silver Carp Otolith. (Left) Sr K α intensity, blue = low, red = high. (Right) Reflected light photomicrograph.

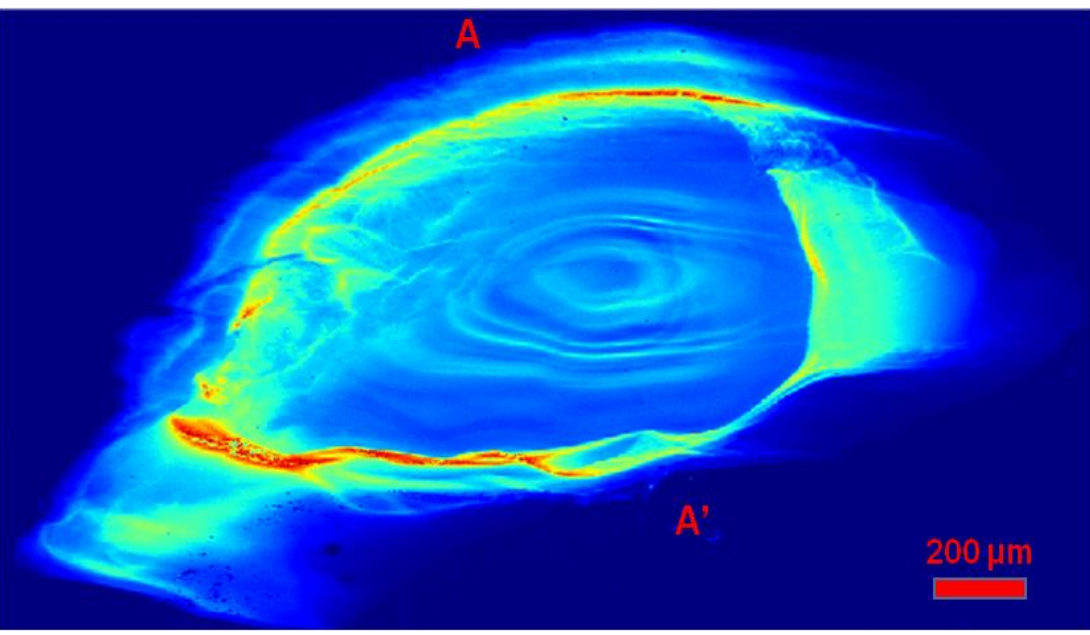
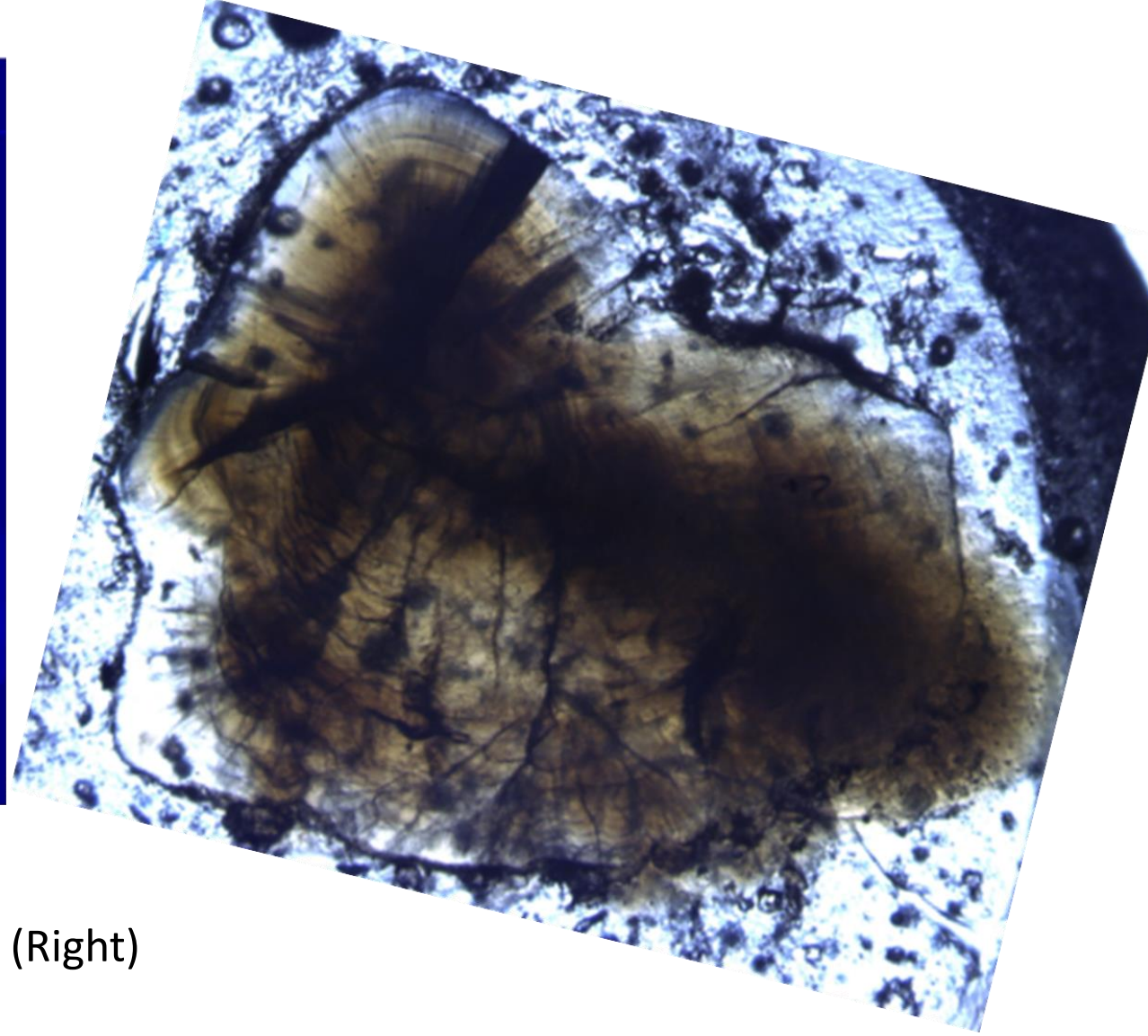


Figure 3: Sample S1 - Silver Carp Otolith. (Left) Sr K α intensity, blue = low, red = high. (Right) Reflected light photomicrograph.

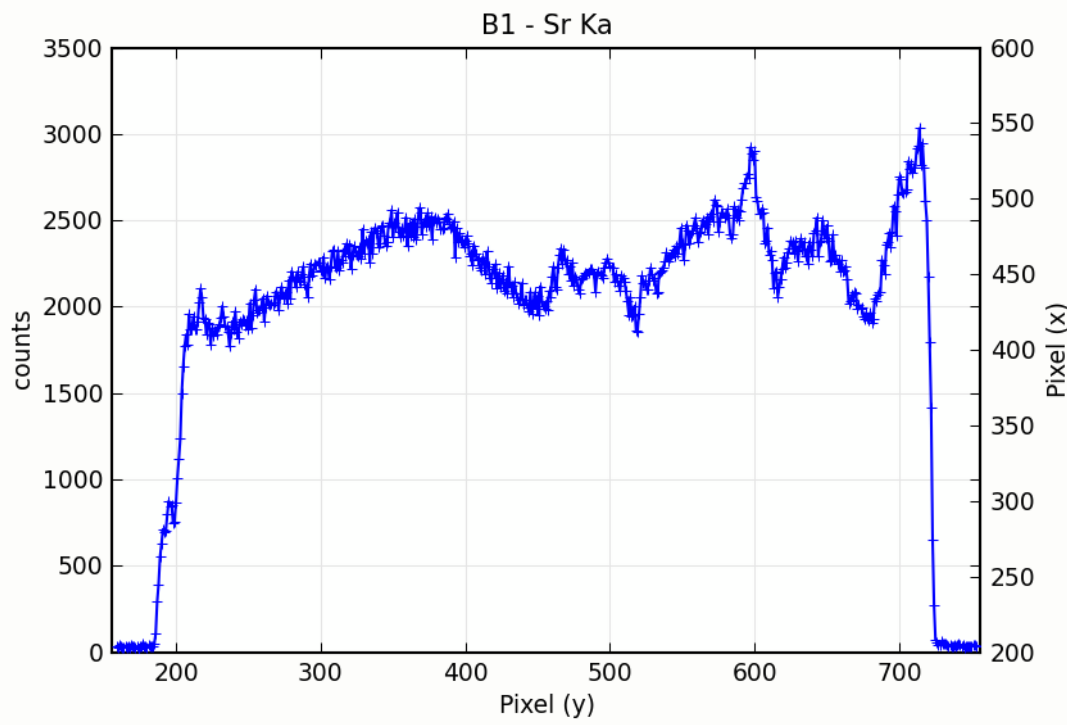
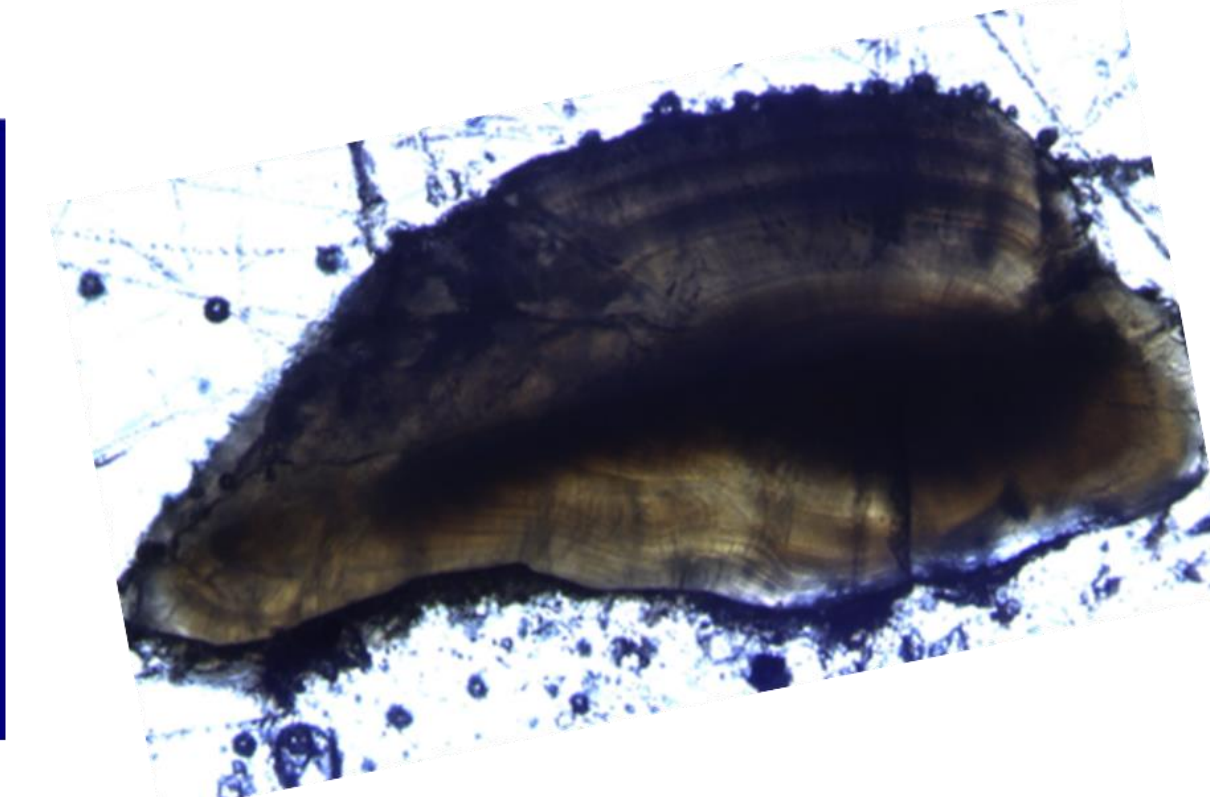
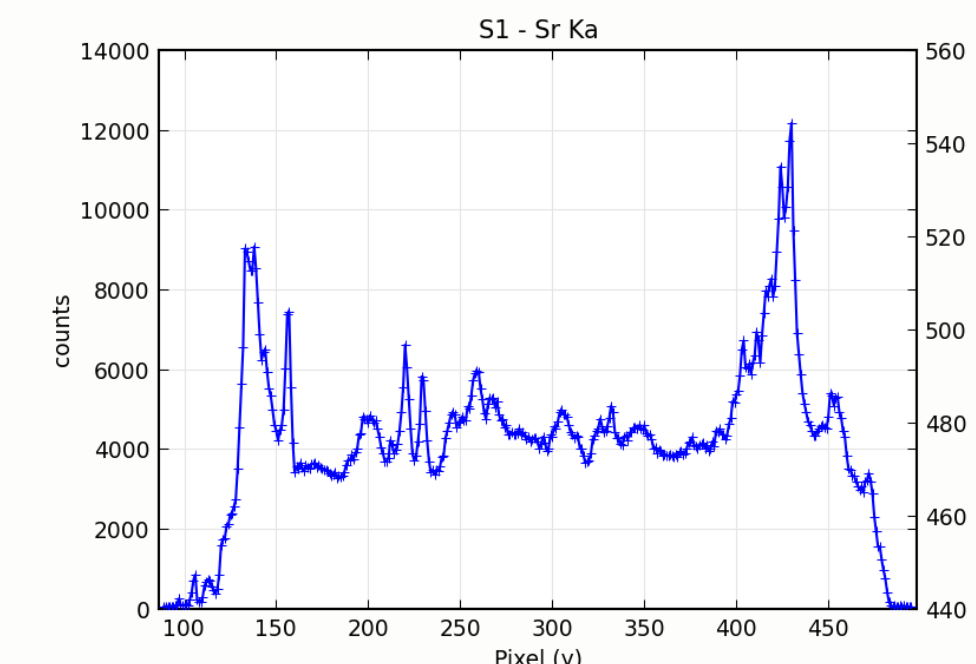
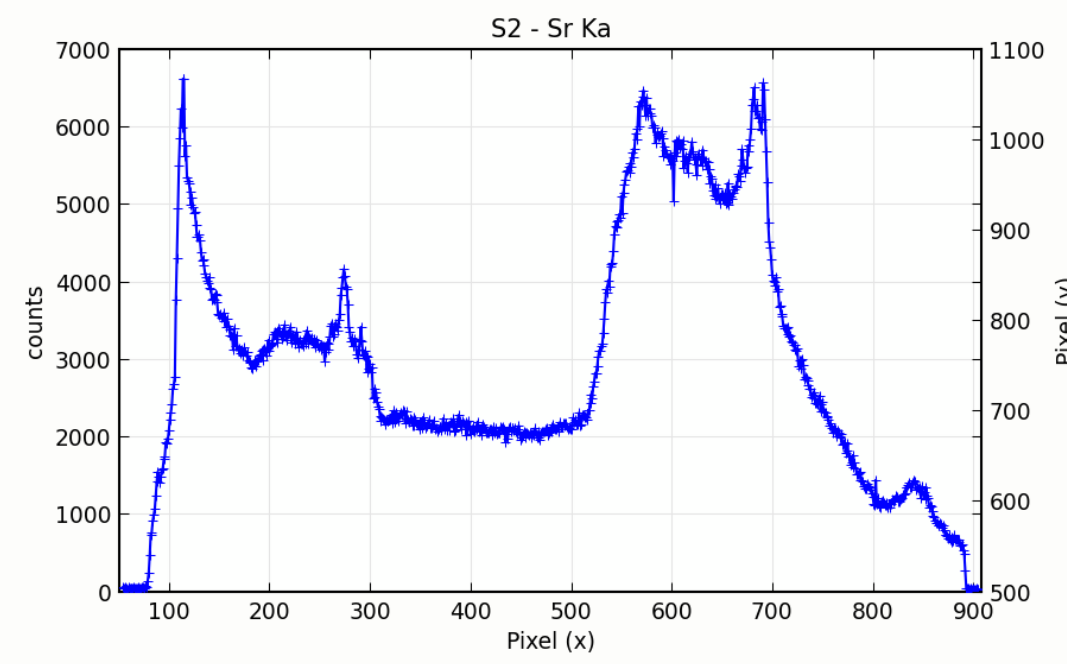


Figure 4: Measured Sr K α intensity measured in otolith samples B1 (top), S2 (lower left) and S1 (lower right) along a transect A-A’ shown in Figures 1-3 left.



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Conclusions

Strontium in otoliths collected from silver and bighead carp from the Illinois River correlate with observed visible growth banding and likely are a direct measure of the Sr/Ca ratio of the ambient water in which the fish traveled through their lifetime. Strontium in silver carp otoliths display higher concentrations than those measured in otoliths from bighead carp large and display significantly higher variability. Sr in bighead carp otoliths is generally more uniformly distributed. We speculate that the differences are consistent with silver carp migrating more broadly than bighead carp, spending time in water systems with higher Sr/Ca water ratios. We further theorize that the data is consistent with silver carp migration downriver into the Mississippi River Basin and then back into the Illinois River (Figure 5). The Mississippi River generally has a much higher molar Sr:Ca ratio than the Illinois River, which likely accounts for the variability in Sr across the silver carp otoliths. This data can then be used to construct a map of the movement of the fish through the Illinois water systems. Once the migratory patterns of Asian carp are known, preventing them from entering Lake Michigan can be achieved.

Future Investigation

Future experiments can be conducted to further our understanding of fish otoliths. Some possible future experimentation includes:

1. Growing a fish from birth in a controlled environment to know the exact age and its relationship to strontium deposits.
2. The effect that temperature has on Strontium concentration in the otolith.
3. The introduction of polluted water in a controlled environment to determine if x-ray fluorescence is able to find differences in the otolith microchemistry.
4. Comparing the Strontium concentration in an otolith to that of the water the fish was extracted from.



Figure 5: Map of the northern Illinois river system (www.fws.gov/midwest/mussel/image_library_maps.html)

Literature Cited

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